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INTRODUCTION

This is the Annual Report for the NASA contract #NAG5-1049 covering the period December 1, 1990 to December 30, 1991.

This report consists of two parts:

I. The narrow-band maximum gain microwave amplifier and

II. The narrow-band low-noise microwave amplifier.

During this year, two graduate students worked diligently to produce some interesting results on the microwave amplifiers. In the beginning of this year, we tried to design and fabricate some solid state devices but were unable to do so because of some unforeseen circumstances.

One of the graduate students is in the process of writing her Master's thesis to be submitted sometime in the month of March, 1992. She is hard at work to get some useful experimental results.

The second graduate student, who has to complete his course work during the Spring semester of 1992, is also working for his Master's degree. Hopefully, his thesis will be ready to be submitted at the end of Summer, 1992.

One other significant outcome of this project is that a paper will be submitted for publication in January, 1992. This paper is on some interesting superconducting electronic devices. The final touches for this paper are being given at present.

I. THE NARROW-BAND MAXIMUM GAIN MICROWAVE AMPLIFIER

I. THE NARROW-BAND MAXIMUM GAIN MICROWAVE AMPLIFIER

A. GENERAL DESCRIPTION

A Narrow-band Amplifier traditionally has a bandwidth of less than 10% . The design procedures for this type of amplifier are similar to the small signal amplifier design except that the scattering, noise figure, and power-gain parameters must be measured at the center frequency of the narrow bandwidth. The maximum power gain G_{max} that can be realized for a microwave amplifier without external feedback is defined as the forward power gain when the input and output are simultaneously and conjugately matched. Conjugately matched conditions mean that the reflection coefficient Γ_s of the source is equal to the conjugate of the input reflection coefficient Γ_{in} , and the reflection coefficient Γ_l of the load is equal to the conjugate of the output reflection coefficient Γ_{out}. These are

$$\Gamma_s = \Gamma_{in}^* \quad \text{and} \quad \Gamma_l = \Gamma_{out}^*$$

The reflection coefficient of the source impedance required to conjugately match the input of the amplifier for maximum power gain is Γ_{sm}, and the reflection coefficient of the load impedance required to conjugately match the output of the amplifier is Γ_{lm}. The matching networks to be designed for narrowband amplifier are shown in Figure 1.

B. DESIGN OF A NARROW-BAND AMPLIFIER FOR MAXIMUM GAIN

HFET-2201, The Hewlett - Packard device, is a gallium arsenide schottky gate field effect transistor (FET). This is designed for consistent broadband or narrow-band operation over the frequency range of 2 GHz to 18 Ghz. The device's superior noise and gain perform-ance, coupled with its wide dynamic range capability make it ideally suited for such applications as ECM, wideband surveillance, and warning systems. In addition, its characteristics lend themselves to ease of circuit design in applications such as radar and communications equipment.

The design of HFET-2201 microwave amplifier at 9 Ghz center frequency consisted of two parts. First, using the s-parameters of the HFET-2201, and the specifications that there must be a maximum gain of 14 dB at 9 GHz, a paper design was realized. This paper design was then converted into a practical design using the actual FET coupled with microstripline circuitry. The entire circuit will then be tested using the Hewlett Packard Automatic Network Analyser (ANA) 8409B.

i. THEORETICAL DESIGN

The S - parameters of the packaged HFET-2201 normalized to 50 Ω at 9 GHz (center frequency) are given by the manufacturer :

$S11 = 0.84 \angle 161°$ $\quad\quad$ $S21 = 1.59 \angle -19°$

$S12 = 0.03 \angle -30°$ $\quad\quad$ $S22 = 0.72 \angle -143°$

A computer program "DES2" was written and used to compute the values of the stability factor K, gain, and the impedances of the input and the output matching networks. The program listing of the "DES2" is given in Appendix A.

The stability factor K determines the stability of the system. If $K>1$, the system is unconditionally stable. If $K<1$, the system is potentially unstable. The stability factor calculated by using "DES2" program for this amplifier at 9 GHz is 1.27. Also, using the same program, the gain of the amplifier is calculated to be 14.1 dB. The source reflection coefficient (Γ_{sm}) of 0.914 $\underline{|-156.58^\circ}$ for maximum available power gain at minimum noise figure and the load reflection coefficient (Γ_{lm}) of 0.8501 $\underline{|152.114^\circ}$ for maximum gain operation are also calculated.

a. INPUT MATCHING NETWORK DESIGN PROCEDURE

1. The input matching circuit must present the optimum source reflection coefficient (0.914 $\underline{|-156.58^\circ}$) to the device input for high gain operation.

2. The matching network should present an equivalent source impedance Zsin.

$$Zsin = Zo\,(1 + \Gamma_{sm})/(1 - \Gamma_{sm}). \qquad \text{------}>(1)$$

Where Z_{sin} = Source input impedance.

Z_o = Characteristic impedance (50 Ω).

$$\Gamma_{sm} = |\Gamma_{sm}| \cos\angle\Gamma_{sm} + j|\Gamma_{sm}| \sin\angle\Gamma_{sm}. \quad \text{--->(2)}$$

Substituting equation(2) in equation(1) and then multiplying the numerator and denominator of the resultant by the conjugate of the denominator results in the source equivalent impedance for maximum power gain :

$$Z_{sin} = \frac{Z_o(1 - |\Gamma_{sm}| + j2\,|\Gamma_{sm}| \sin\angle\Gamma_{sm})}{(1 + |\Gamma_{sm}| - 2\,|\Gamma_{sm}| \cos\angle\Gamma_{sm})}.$$

$$= 10.636 \angle{-77.36^\circ}.$$

$$Y_{sin} = 1/Z_{sin}$$

$$= 0.094 \angle 77.36^\circ.$$

3. An open stub of length 3 λ/8 works like a shunt inductor with a characteristic impedance of

$$Z_{o1} = 1/\mathrm{Im}[Y_{sin}]$$

$$= 10.9\ \Omega.$$

4. A transmission line with $\lambda/4$ in length will match the 50 Ω source resistance with the real part of Ysin. Its characteristic impedance is

$$Zo2 = \sqrt{(50/\mathrm{Re}[Ysin])}$$
$$= 49.22\ \Omega.$$

b. OUTPUT MATCHING NETWORK DESIGN PROCEDURE

1. The output matching circuit must present the optimum load reflection coefficient ($0.8501\ \angle 152.114°$) to the device output for high gain operation.

2. The load equivalent impedance for maximum power gain is

$$Zlo = 13.088\ \angle 70.86°.$$
$$Ylo = 1/Zlo$$
$$= 0.0764\ \angle -70.86°.$$

3. An open stub of length $3\lambda/8$ works like a shunt inductor with a characteristic impedance of

$$Zo3 = 13.857\ \Omega.$$

4. A quarter-wave transformer is needed to transform the load equivalent impedance to the load resistance of 50 Ω. Its characteristic impedance is

$$Zo4 = \sqrt{(Zo/Im[Ylo])}$$
$$= 44.64\ \Omega.$$

The designed matching networks for the HFET-2201 amplifier are shown in Fig.2.

Figure 2 can be modified as shown in Fig. 3 for symmetry and balance in microstrip lines. The open stub Z01 of impedance 10.9 Ω in Figure 2 is converted into two parallel open stubs Z1, Z2 of equal impedance as shown in Fig. 3. Similarly, Z03 is also converted into two parallel open stubs Z4 and Z5.

c. MICROSTRIP DESIGN

Using Duriod as the microstrip substrate with relative dielectric constant Er of 10.2 and thickness of 25 mils, the effective dielectric constant Ereff and the width of the microstripline for various impedances are found by using the computer program "IMPDE7".

The listing of this program is given in Appendix A. Ereff, width and lengths of the microstrip for the original and modified matching network elements are given in Tables 1 and 2 respectively. The modified matching network elements Z1, Z2, Z3, Z4, Z5 and Z6 with their lengths and widths are shown in Figure 4. The wavelength (λ) was found by using the expression

$$\lambda = C/f \sqrt{Ereff} .$$

Where C is the velocity of light (3×10^{10} cm/Sec).
f is the frequency of operation (9 GHz) of the HFET-2201.

ii. PRACTICAL DESIGN

In the paper design, the lengths and configurations of the microstriplines were determined. These lengths and configurations were then realized by fabricating the microstrip circuitry in the solid state laboratory. The FET was then carefully mounted on to the circuitry to obtain the amplifier circuit. The circuit realization pattern on duroid substrate is shown in Figure 4A. The input circuit occupies an area of 343.18 mil by 375.74 mil, while the output circuit takes 315.02 mil by 387.54 mil area.

STEP 1. Using the configuration of the circuit in Figure 4A the transmission lines were first drawn to an expanded scale of 1" to 10". A pattern of this configuration was then cut out on a sheet of Rubylith. Once the pattern was satisfactory, it was then attached to a light-box and a photograph of this configuration was taken. The photograph was taken such that the image was reduced to the actual size of the circuit which was calculated in the paper design.

STEP 2. The film was then taken to the dark-room where the negatives were developed. Two exposures were taken to ensure that a good result would be obtained. Then the exposures were placed in a developing solution until the film was developed satisfactorily. After a satisfactory picture was obtained, the film was washed and placed in a fixing solution which stopped further developing and gave the fixed picture. This slide was then used as a mask for the remainder of the experiment.

STEP 3. The mask was then used to obtain the actual circuit which consisted of copper on a substrate of duroid. A piece of duroid was cut from a sheet to about the size of the mask, and then taken to the Solid State Laboratory for processing. The duroid was first cleaned using acetone followed by methanol, and then washed with deionized water. The duroid was then blow-dried using an air gun. Microposit photoresist was then smeared over the entire surface of the duroid and it was then spun for 20 seconds at 4,000 r.p.m. in the spinner. This procedure allowed a thin film of photoresist of 1.2 microns to be evenly distributed over the surface of the duroid. The duroid was then pre-baked at 96 degrees celsius for 20 minutes. At this time the duroid was ready to be mask-aligned. In this process , the mask was placed over the duroid and exposed to ultraviolet light for 15 seconds, using the mask-aligner. The Duroid was then placed into a Microposit 351 Developing solution where an image of the mask was realized. The duroid was then placed in a solution of Toluene where the image was fixed and hardened. At this time, the duroid was washed with de-ionized water and then blow-dried. It was then post-baked at 120 degrees celsius for half an hour.

STEP 4. Since the back portion of the Duroid had to remain copper coated, it was smeared with photoresist and then baked for half an hour. This procedure ensured that the back of the duroid would not be attacked during the etching procedure.

STEP 5. The duroid was then placed in an etching solution which consisted of a mixture of iron chloride and water. This etchant removed all of the copper from around the image of the copper stripline and did not attack the copper at the back of the duroid. In the end, all that was left was the copper stripline pattern in the front portion, and a copper coated back portion. This back portion acted as a ground plane.

STEP 6. The FET was then mounted on the duroid with the gate and the drain terminals fixed to the ends of the microstrip lines and the source was attached to the back of the duroid. The terminals were fixed to the duroid using conducting epoxy.

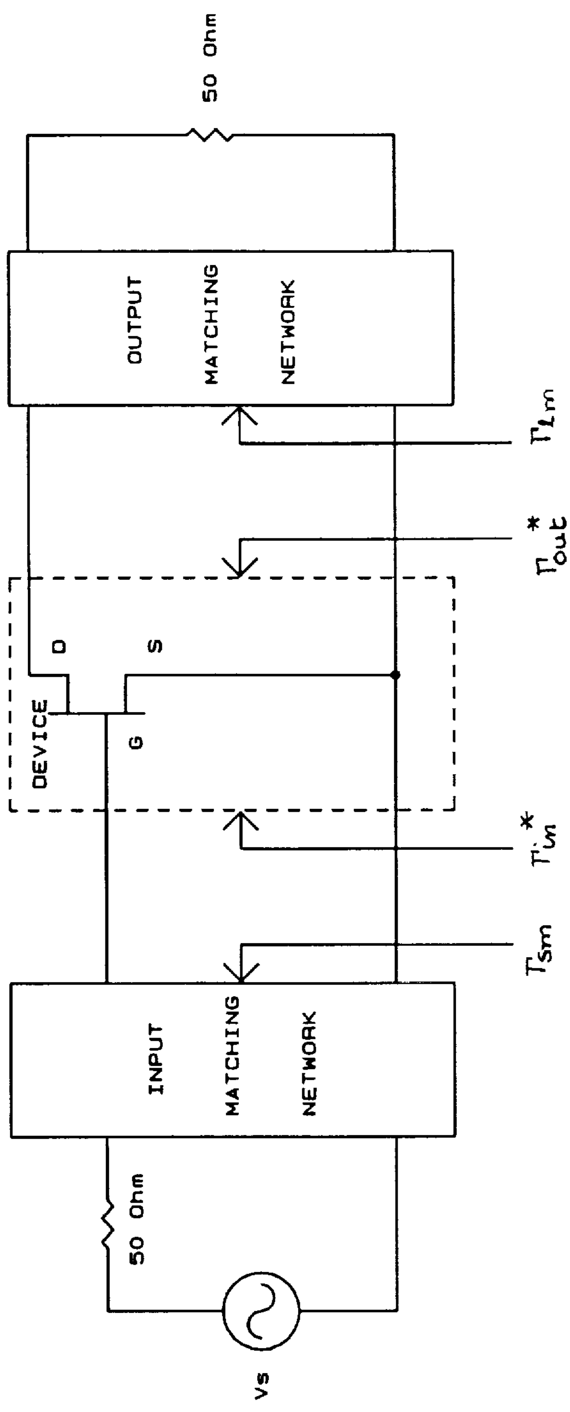
STEP 7. The circuit will then be tested on the Hewlett Packard Automatic Network Analyzer (ANA) 8409B.

Table 1.

ELEMENT	VALUE (Ω)	WIDTH (mil)	Ereff	g (mil)	LENGTH (mil)
Z01	10.9	224.0	8.595	447.59	(3/8) g = 187.85
Z02	49.22	24.0	6.85	501.42	(1/4) g = 125.35
Z03	13.858	165.7	8.34	454.32	(3/8) g = 170.37
Z04	44.64	29.1	6.97	497.16	(1/4) g = 124.29

Table 2.

ELEMENT	VALUE (Ω)	WIDTH (mil)	Ereff	g (mil)	LENGTH (mil)
Z1=2*Z01	21.8	92.3	7.83	468.99	175.87
Z2=2*Z01	21.8	92.3	7.83	468.99	175.87
Z3=Z02	49.22	24.0	6.85	501.42	125.35
Z4=2*Z03	27.806	65.2	7.54	477.92	179.22
Z5=2*Z03	27.806	65.2	7.54	477.92	179.22
Z6=Z04	44.64	29.1	6.97	497.16	124.29



50 Ohm
OUTPUT
MATCHING
NETWORK
DEVICE
D
S
G
INPUT
MATCHING
NETWORK
50 Ohm
Vs

Fig.1

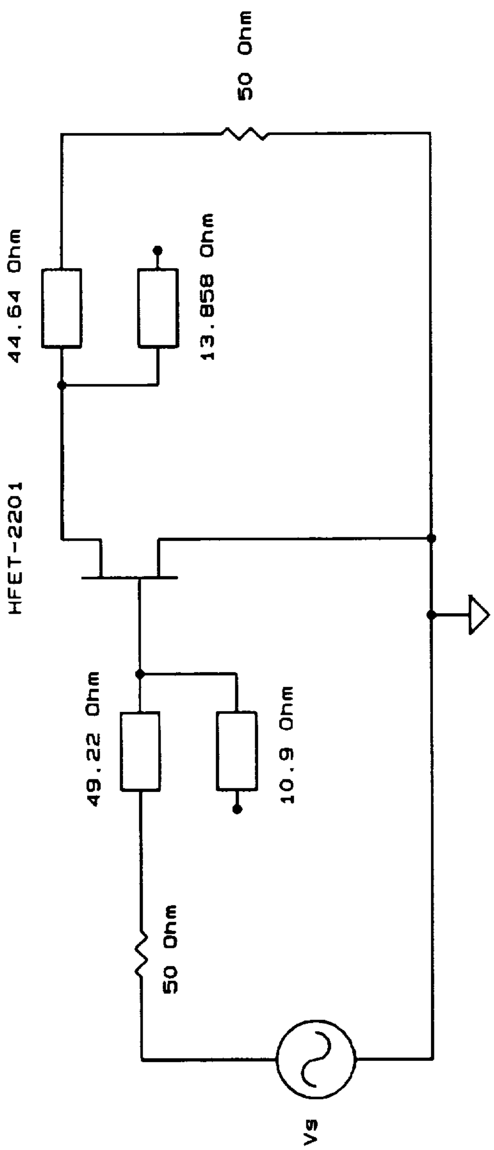

50 Ohm
44.64 Ohm
13.858 Ohm
HFET-2201
49.22 Ohm
10.9 Ohm
50 Ohm
Vs

Fig.2

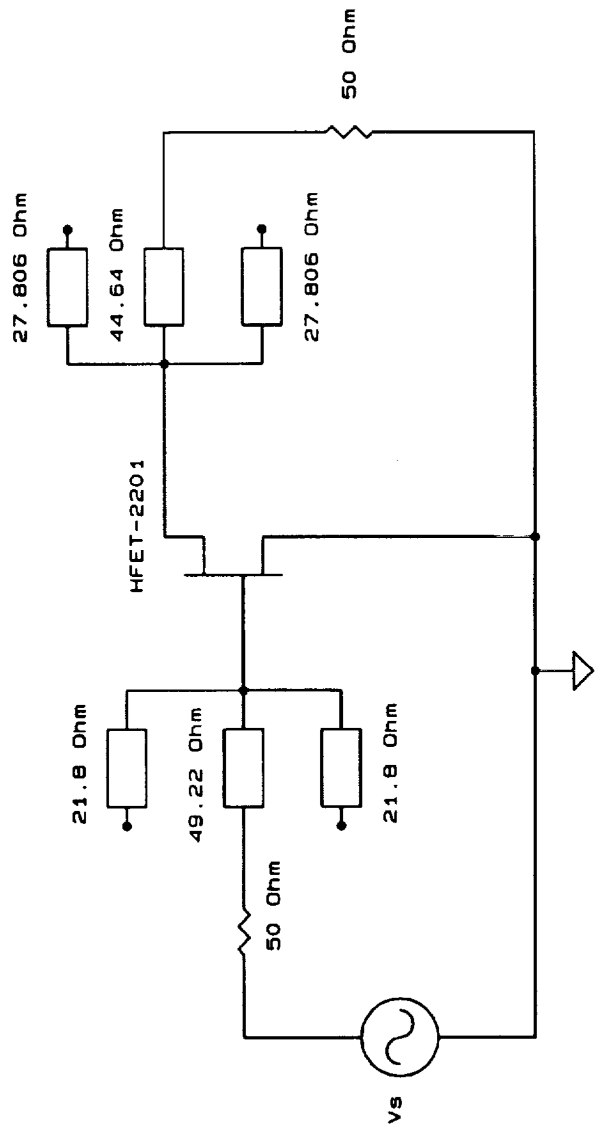

50 Ohm
27.806 Ohm
44.64 Ohm
27.806 Ohm
HFET-2201
21.8 Ohm
49.22 Ohm
21.8 Ohm
50 Ohm
Vs

Fig.3

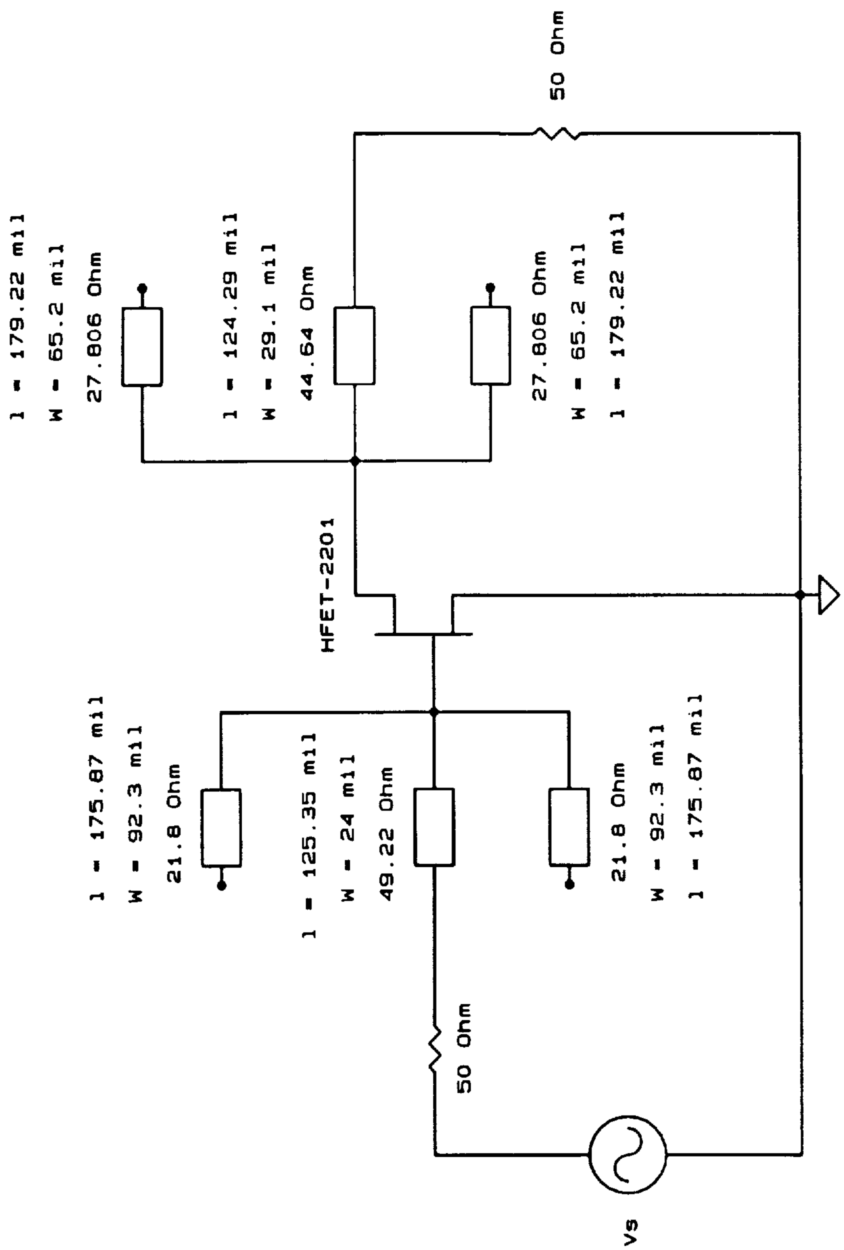

l = 179.22 mil
W = 65.2 mil
27.806 Ohm
l = 124.29 mil
W = 29.1 mil
44.64 Ohm
27.806 Ohm
W = 65.2 mil
l = 179.22 mil
50 Ohm
HFET-2201
l = 175.87 mil
W = 92.3 mil
21.8 Ohm
l = 125.35 mil
W = 24 mil
49.22 Ohm
21.8 Ohm
W = 92.3 mil
l = 175.87 mil
50 Ohm
Vs

Fig.4

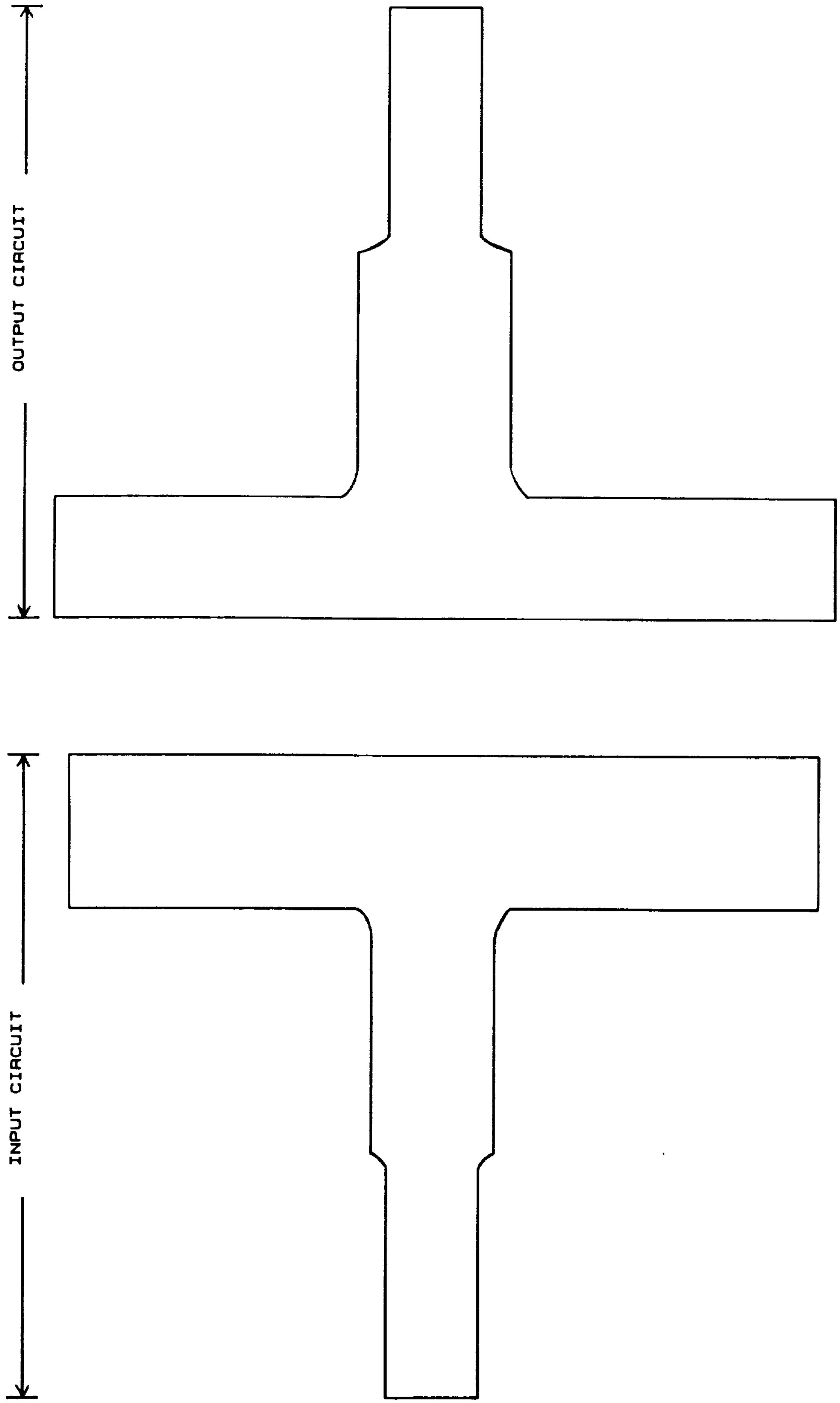


FIG.4A. MICROSTRIP DESIGN

II. THE NARROWBAND LOW-NOISE MICROWAVE AMPLIFIER

II THE NARROWBAND LOW-NOISE MICROWAVE AMPLIFIER

Because of the increasing need for Microwave amplifiers in rapidly developing areas such as remote sensing, spaceborne and terrestrial communication systems, airborne and land based radar systems, microwave amplifier design is increasingly becoming a very important part of electrical engineering.

Several Distinct microwave amplifier design procedures exist based on the anticipated use and application environment of the amplifier. Table 3 shows some of the more commonly used microwave amplifiers tabulated according to their design procedure.

This section of the report is based on the design of a low-noise microwave amplifier using the **HP HXTR-6104** low-noise transistor.

- Microwave Amplifiers
  - Bandwidth
    - Narrowband Amplifiers
    - Broadband Amplifiers
  - Circuit Structure
    - Balanced Amplifier
    - Feedback Amplifier
    - Reflection Amplifier
    - Stripline Amplifier
  - Function
    - Small-Signal Amplifier
    - Large-Signal Amplifier
    - High-Gain Amplifier
    - High-Power Amplifier
    - Low-Noise Amplifier

Table 3. Microwave amplifiers tabulated according to design procedure.

Amplifier Stability:

One of the basic and most critical factors in the design consideration of any microwave amplifier is the amplifier stability. The stability of an amplifier is its resistance to oscillation, and can be determined by the accurate measurement of its (scattering) S-parameters and the impedance of its simulated source and loads. an amplifier will become unstable if either its source or load has a negative resistance, or when either of the scattering parameters S_{11} and/or S_{22} is greater than unity.

These areas of operation of an amplifier should usually be avoided, although it can be shown that even with negative resistances, the amplifier can still be operated in a very small stable region if other design factors are taken into consideration. The stability of a microwave amplifier can be subdivided into two types.

1. **Unconditional Stability:**

   The amplifier is unconditionally stable if the real parts of the impedances at both its input and output ports are greater than zero for **ALL** positive real source and load impedances at a specific frequency.

2. **Conditional Stability:**

   The amplifier is conditionally stable if the real part of the impedances at both its input and output ports are greater than zero for **SOME** positive real source and load impedances at a particular frequency.

   Positive real source and load impedances mean that :

$$\Gamma_s \quad \text{and} \quad \Gamma_L \quad \preceq \quad 1$$

For unconditional stability, the magnitudes of S_{11} , S_{22} , Γ_ϵ , and Γ_{out} must all be smaller than 1, and at the same time, the device's stability factor **K** must be greater than unity.

$$K = \frac{1+|\Delta|^2-|S_{11}|^2-|S_{22}|^2}{2|S_{11}S_{21}|} > 1$$

Where $|\Delta| = |S_{11}S_{22}-S_{12}S_{22}| < 1$

The input reflection coefficient: $$\Gamma_{\epsilon}=S_{11}+\frac{S_{12}S_{21}\Gamma_L}{1-S_{22}\Gamma_L}$$

The output reflection coefficient: $$\Gamma_{out}=S_{22}+\frac{S_{12}S_{21}\Gamma_s}{1-S_{11}\Gamma_s}$$

Stability circles which separate the input or output planes into stable and potentially unstable regions can be drawn on a Smith chart or calculated. A stability circle drawn on the output plane shows all loads that will cause oscillation by providing negative real input impedance, while the stability circle drawn on the input plane shows all loads that cause oscillation by supplying negative real output impedance. The regions of instability occur within the circles.

The boundary conditions for stability are: $$|\Gamma_{\epsilon}|=|S_{11}+\frac{S_{12}S_{21}\Gamma_L}{1-S_{22}\Gamma_L}|\leq 1$$

and $$|\Gamma_{out}|=|S_{22}+\frac{S_{12}S_{21}\Gamma_s}{1-S_{11}\Gamma_s}|\leq 1$$

The radius of the Γ_s circle = $$r_s=\frac{S_{11}S_{21}}{||S_{11}|^2-|\Delta|^2|}$$

The center of the Γ_s circle = $$C_s=\frac{C_s^*}{|S_{11}|^2-|\Delta|^2|}$$

The radius of the Γ_L circle = $$r_L=\frac{|S_{12}S_{21}|}{||S_{22}|^2-|\Delta|^2|}$$

The center of the Γ_L circle = $$C_L=\frac{C_L^*}{|S_{22}|^2-|\Delta|^2}$$

where

$$\Delta = S_{11}S_{22} - S_{12}S_{21}$$

$$C_s = S_{11} - \Delta S_{22}^*$$

$$C_L = S_{22} - \Delta S_{11}^*$$

Finally, The stability Criteria are as follows:

a: Unconditional stability

$K > 1$ and $|\Delta| < 1$

$||C_s| - r_s| > 1$ for $|S_{22}| < 1$

$||C_L| - r_L| > 1$ for $|S_{11}| < 1$

b: Conditional stability

$K > 1$ and $|\Delta| < 1$

$||C_s| - r_s| < 1$ for $|S_{22}| < 1$

$||C_L| - r_L| < 1$ for $|S_{11}| < 1$

c: Potential instability

$$K > 1 \quad \text{and} \quad |\Delta| < 1$$

or

$$K < 1 \quad \text{and} \quad |\Delta| < 1$$

The stability conditions can be shown Graphically on a Smith chart. To achieve unconditional stability, all passive source and load impedances must produce stability circles which are completely outside the Smith chart as shown in **figure 5.** A potentially unstable situation arises when the stability circle overlaps the Smith chart as shown in **figure 6.**

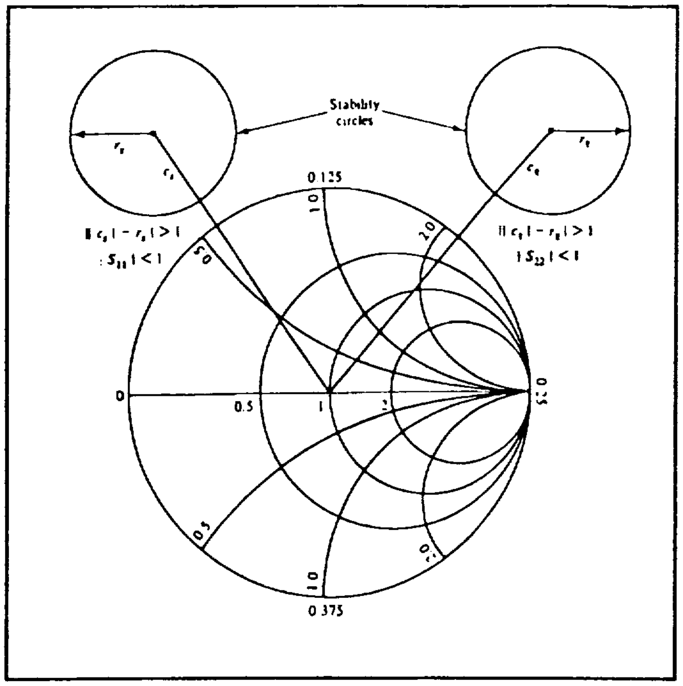


Figure 5. Locations of Unconditional stability circles on the Smith chart.

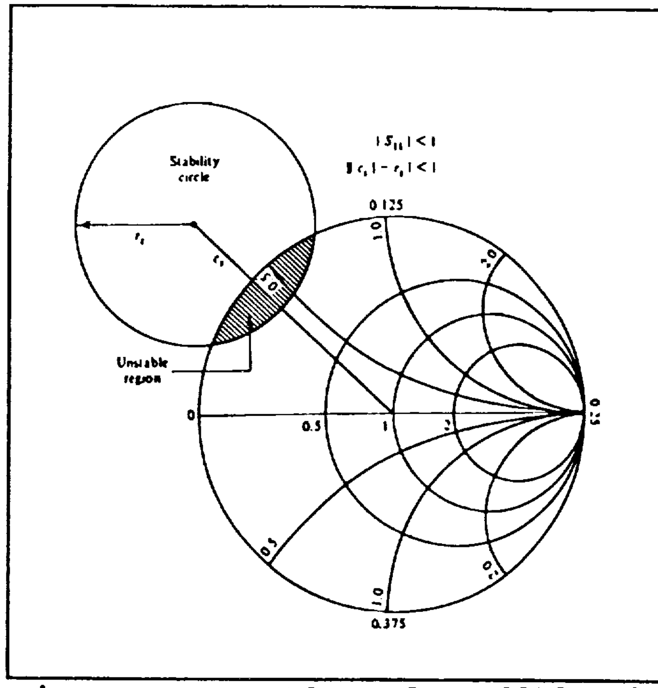


Figure 6. Location of Conditional stability circle on the Smith chart.

In the general design procedure for microwave, the maximum gain and the minimum noise-figure are equally important, but because of conflicting design constraints, the maximum gain and minimum noise-figure cannot be achieved simultaneously. Therefore, a trade-off is usually made between high-gain and low-noise, often sacrificing one for the other. In some amplifier stages such as the Pre-amplifier, the minimum noise-figure will be given more design consideration than the power-gain. The basic goal of the low-noise design procedure is to design input and output matching networks, which will allow the device to be operated at its minimum noise-figure. The design parameters and final configuration of the low-noise amplifier matching networks are as shown in **figure 7.**

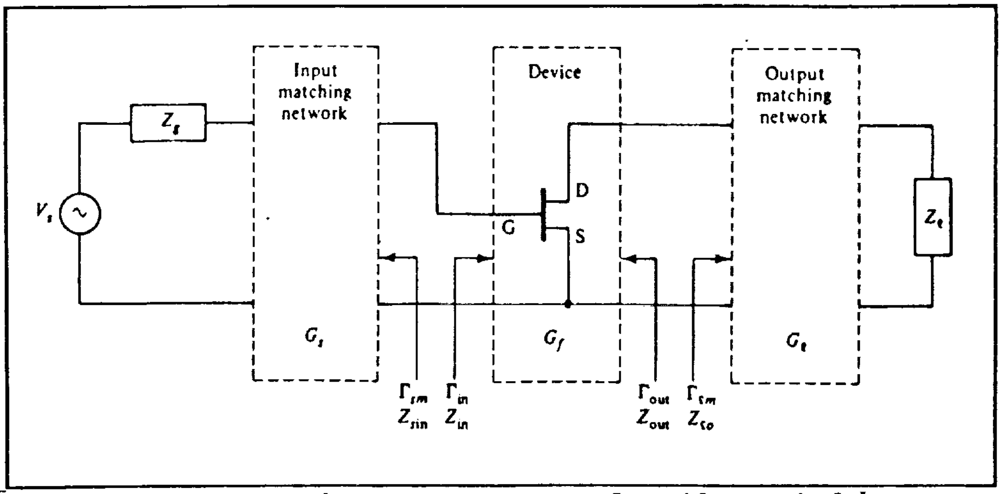


Figure 7. The design parameters for the matching networks of the low-noise amplifier

For minimum noise-figure, the source equivalent impedance is given as follows:

$$Z_{sn}=\frac{Z_o(1-|\Gamma_o|^2)+j2Z_oSin(\angle\Gamma_o)}{1+|\Gamma_o|^2-2|\Gamma|Cos(\angle\Gamma_o)}$$

where Γ_o is the optimum source reflection coefficient for minimum noise-figure (usually supplied by the manufacturer of the device).

The load equivalent impedance for minimum noise-figure is given as follows:

$$Z_{Ln}=\frac{Z_o(1-|\Gamma_L|^2+j2Z_oSin(\angle\Gamma_L)}{1+|\Gamma_L|^2-a|\Gamma_L|\cos(\angle\Gamma_L)}$$

where Γ_L is the optimum load reflection coefficient for minimum noise-figure $F_{\min}$.

Using the design equations supplied, the design steps and results for designing a Narrowband amplifier for minimum noise-figure using the HP HXTR-6104 are presented. The design procedure is subdivided into two parts.

Part a: The design of the input matching network.

Part b: The design of the output matching network.

A: The design of the input matching network.

Step 1. Determine the source equivalent impedance for minimum noise-figure.

$$Z_{sn}=\frac{Z_o(1-|\Gamma_o|^2)+j2Z_oSin(\angle\Gamma_o)}{1+|\Gamma_o|^2-2|\Gamma_o|\cos(\angle\Gamma_o)}$$

$$Z_{sn}=\frac{50(1-|0.323|^2)+j100\sin(94)}{1+|0.323|^2-2(0.323)\cos(94)} \quad = \quad \frac{109.348\angle 65.82°}{1.149}$$

$$Z_{sn}=38.97+j86.78\Omega$$

Step 2. Convert Z_{sn} to Y_{sn}

$$Y_{sn}=\frac{1}{Z_{sn}} \quad =\frac{1}{38.97+j86.79} \quad = \quad 0.0043-j0.0096℧$$

Step 3. Use a three-eighths wavelength open-circuited stub which provides a shunt inductance of $-jY_o$.

$$Z_{o1}=\frac{1}{Y_o} \quad = \quad \frac{1}{0.0096}=104.28\Omega$$

Step 4. Use a quarter -wavelength transformer to transform the load resistance to the load equivalent conductance.

$$Z_{o2}=\sqrt{\frac{Z_o}{Y_o}} \quad =\sqrt{\frac{50}{0.0043}}=107.83\Omega$$

where Z_o is the characteristic Impedance.

B: The design of the output matching network.

Step 1. Determine the load equivalent impedance for the minimum noise-figure.

$$Z_{Ln}=\frac{Z_o(1-|\Gamma_L|^2)+j2Z_oSin(\angle\Gamma_L)}{1+|\Gamma_L|^2-2|\Gamma_L|Cos(\angle\Gamma_L)}$$

$$=\frac{50(1-|0.6871|^2)+j100\sin(46.21)}{1+|0.6871|^2-|0.6871|\cos(46.21)}$$

$$=50.636+j138.52\Omega$$

Step 2. Convert Z_{Ln} to Y_{Ln}

$$Y_{Ln}=\frac{1}{Z_{Ln}}$$

$$=\frac{1}{50.636+j138.52} \qquad =0.0023-j0.0064\mho$$

Step 3. Use a three-eighths wavelength open-circuited stub which provides a shunt inductance of $-jY_o$.

$$Z_{o1}=\frac{1}{Y_o} \qquad =\frac{1}{0.0064}=157.02\Omega$$

Step 4. Use a quarter-wavelength transformer to match the load equivalent impedance to the load resistance.

$$Z_{o2}=\sqrt{\frac{Z_o}{Y_o}} \qquad =\sqrt{\frac{50}{0.0023}}=146.55\Omega$$

The final matching network is shown in **figure 8.**

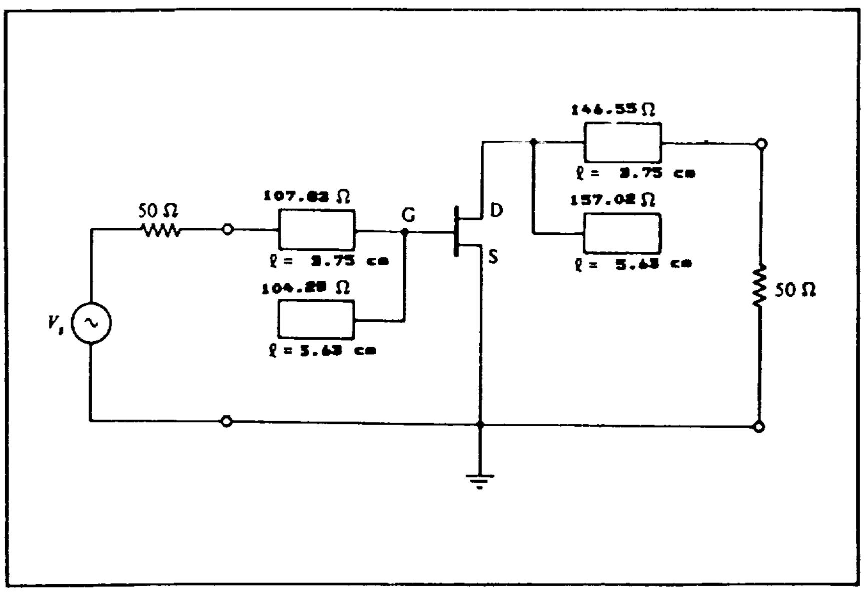


Figure 8. The designed matching networks of the low-noise amplifier

Appendix B is a listing of a pascal program written on the HP-3000 computer to calculate all of the design parameters that are needed to design a low-noise amplifier using the Scattering parameters of the active device. This program can also be used to design an amplifier using the maximum gain procedure.

APPENDIX A

```
EM Program: Design of a GaAs FET Amplifier for Maximum Gain
RINT "Enter the Device name" : PRINT
NPUT DEVICE
RINT "Enter S-parameters"
INPUT S11M,S11A,S21M,S21A,S12M,S12A,S22M,S22A
PRINT "Enter Frequency (GHz)"
INPUT FREQUENCY
A=S11M*S22M
A1=S11A+S22A
B=A1*3.14/180
C=A*COS(B)    : D=A*SIN(B)
E=S21M*S12M
F1=S21A+S12A    : F= F1*3.14/180
G=E*COS(F)    : H=E*SIN(F)
DELT1=C-G
DELT2=D-H
DELTM=SQR(DELT1^2+DELT2^2)
 DELTA=(ATN(DELT2/DELT1))*180/3.14
 IF DELT1<0 AND DELT2<0 THEN DELTA=DELTA-180
 IF DELT1<0 AND DELT2>0 THEN DELTA=DELTA+180
 K=(1+DELTM^2-S11M^2-S22M^2)/(2*S12M*S21M)
 IF K<1 THEN 1350
 GAIN=10*LOG(S21M/S12M)*(K-SQR(K^2-1))
 PRINT DELTM,DELTA,K
 B1=1+S11M^2-S22M^2-DELTM^2
 B2=1+S22M^2-S11M^2-DELTM^2
 S22A1=-S22A : M=DELTM*S22M  : N=DELTA+S22A1 : O=N*3.14/180
 P=M*COS(O) : Q=M*SIN(O) : R=S11M*COS(S11A*3.14/180)
 S=S11M*SIN(S11A*3.14/180)
 REC1=R-P : IMC1=S-Q
 C1M=SQR((R-P)^2+(S-Q)^2) : C1A=(ATN((S-Q)/(R-P)))*180/3.14
 IF REC1<0 AND IMC1<0 THEN C1A=C1A-180
 IF REC1<0 AND IMC1>0 THEN C1A=C1A+180
 T=DELTM*S11M : U=DELTA-S11A : V=U*3.14/180 : W=T*COS(V) : X=T*SIN(V)
 Y=S22M*COS(S22A*3.14/180) : Z=S22M*SIN(S22A*3.14/180)
 REC2=Y-W : IMC2=Z-X
 C2M=SQR((W-Y)^2+(X-Z)^2) : C2A=(ATN((X-Z)/(W-Y)))*180/3.14
 IF REC2<0 AND IMC2<0 THEN C2A=C2A-180
 IF REC2<0 AND IMC2>0 THEN C2A=C2A+180
 COEFF=(B1^2-4*C1M^2)
 IF COEFF<0 THEN 340
 FACTOR=SQR(COEFF)
 IF B1>0 THEN 300
 RADICALM=B1+FACTOR
 GOTO 310
 RADICALM=B1-FACTOR
 MULTM=RADICALM*C1M
 MULTA=-C1A
 GOTO 430
 FACTOR=SQR(-COEFF)
 RADICALM=SQR(B1^2+FACTOR^2)
 IF B1>0 THEN 390
```

```
RADICALA=(ATN(FACTOR/B1))*180/3.14
IF B1<0 AND FACTOR<0 THEN RADICALA=RADICALA-180
IF B1<0 AND FACTOR>0 THEN RADICALA=RADICALA+180
GOTO 410
RADICALA=(ATN(-FACTOR/B1))*180/3.14
GOTO 372
MULTM=RADICALM*C1M
MULTA=RADICALA-C1A
TSMM=MULTM/(2*C1M^2)
TSMA=MULTA
ZO=50
IMZSIN=(2*TSMM*SIN(TSMA*3.14/180))*ZO/(1+TSMM^2-2*TSMM*COS(TSMA*3.14/180))
REZSIN=(ZO*(1-TSMM^2))/(1+TSMM^2-2*TSMM*COS(TSMA*3.14/180))
ZSINM=SQR(IMZSIN^2+REZSIN^2)
ZSINA=(ATN(IMZSIN/REZSIN))*180/3.14
IF REZSIN<0 AND IMZSIN<0 THEN ZSINA=ZSINA-180
IF REZSIN<0 AND IMZSIN>0 THEN ZSINA=ZSINA+180
YSINM=1/ZSINM
YSINA=-ZSINA
REYSIN=YSINM*COS(YSINA*3.14/180)
IMYSIN=YSINM*SIN(YSINA*3.14/180)
ZO1=1/ABS(IMYSIN)
IMPE=ZO/ABS(REYSIN)
ZO2=IMPE^.5
OPCOEFF=(B2^2-4*C2M^2)
IF OPCOEFF<0 THEN 770
OPFACTOR=SQR(OPCOEFF)
IF B2>0 THEN 730
OPRADICALM=B2+OPFACTOR
GOTO 740
OPRADICALM=B2-OPFACTOR
OPMULTM=OPRADICALM*C2M
OPMULTA=-C2A
GOTO 850
OPFACTOR=SQR(-OPCOEFF)
OPRADICALM=SQR(B2^2+OPFACTOR^2)
IF B2>0 THEN 820
OPRADICALA=(ATN(OPFACTOR/B2))*180/3.14
IF B2<0 AND OPFACTOR<0 THEN OPRADICALA=OPRADICALA-180
IF B2<0 AND OPFACTOR>0 THEN OPRADICALA=OPRADICALA+180
GOTO 830
OPRADICALA=(ATN(-OPFACTOR/B2))*180/3.14
GOTO 802
OPMULTM=OPRADICALM*C2M
OPMULTA=OPRADICALA-C2A
TLMM=OPMULTM/(2*C2M^2)
TLMA=OPMULTA
IMZLO=(2*TLMM*ZO*SIN(TLMA*3.14/180))/(1+TLMM^2-2*TLMM*COS(TLMA*3.14/180))
REZLO=ZO*(1-TLMM^2)/(1+TLMM^2-2*TLMM*COS(TLMA*3.14/180))
ZLOM=SQR(IMZLO^2+REZLO^2)
ZLOA=(ATN(IMZLO/REZLO))*180/3.14
IF REZLO<0 AND IMZLO<0 THEN ZLOA=ZLOA-180
IF REZLO<0 AND IMZLO>0 THEN ZLOA=ZLOA+180
YLOM=1/ZLOM
YLOA=-ZLOA
REYLO=YLOM*COS(YLOA*3.14/180)
IMYLO=YLOM*SIN(YLOA*3.14/180)
MZ1=1/ABS(IMYLO)
OUTZ=ZO/ABS(REYLO)
MZ2=SQR(OUTZ)
```

```
1 LPRINT"******************* RESULTS ******************"
5 LPRINT TAB(10);"Device is  HFET - ";TAB(31);DEVICE
0 LPRINT "Given s-parameters are:"
5 LPRINT
0 LPRINT TAB(5);"s11m";TAB(20);"s11a";TAB(35);"s21m";TAB(50);"s21a"
3 LPRINT
5 LPRINT TAB(5);S11M;TAB(20);S11A;TAB(35);S21M;TAB(50);S21A  : LPRINT
6 LPRINT TAB(5);"s12m";TAB(20);"s12a";TAB(35);"s22m";TAB(50);"s22a" : LPRINT
8 LPRINT TAB(5);S12M;TAB(20);S12A;TAB(35);S22M;TAB(50);S22A : LPRINT
9 LPRINT
0 LPRINT TAB(7);"k";TAB(20);"gain";TAB(35);"frequency" : LPRINT
2 LPRINT TAB(7);K;TAB(20);GAIN;TAB(35);FREQUENCY  : LPRINT
5 LPRINT
0 LPRINT TAB(5);"magnitude of delta";TAB(30);"angle of delta" : LPRINT
5 LPRINT TAB(10);DELTM;TAB(35);DELTA : LPRINT
6 LPRINT
0 LPRINT TAB(5);"B1";TAB(20);"B2" :LPRINT
2 LPRINT TAB(5);B1;TAB(20);B2 : LPRINT :LPRINT
0 LPRINT TAB(5);"magnitude of C1";TAB(25);"angle of C1";TAB(45);"magnitude of
";TAB(65);"angle of C2"
1 LPRINT
5 LPRINT TAB(10);C1M;TAB(30);C1A;TAB(50);C2M;TAB(70);C2A : LPRINT
0 LPRINT
0 LPRINT "******** input matching network design **********":LPRINT
5 LPRINT
0 LPRINT " source reflection coefficient ":LPRINT
2 LPRINT TAB(5);"magnitude of Tsm";TAB(35);"angle of Tsm" : LPRINT
3 LPRINT TAB(10);TSMM;TAB(40);TSMA : LPRINT : LPRINT
0 LPRINT "determination of source equivalent impedance"
5 LPRINT
0 LPRINT TAB(5);"magnitude of Zsin";TAB(35);"angle of Zsin" : LPRINT
2 LPRINT TAB(10);ZSINM;TAB(40);ZSINA : LPRINT : LPRINT
5 LPRINT "impedances of the input matching network:" : LPRINT
7 LPRINT TAB(5);"Impedance associated with  3/8   is Zo1";TAB(45);"Impedance
ociated with 1/4  is Zo2"  : LPRINT
9 LPRINT TAB(15);ZO1;TAB(55);ZO2   : LPRINT
0 LPRINT
0 LPRINT
0 LPRINT "********  output matching network design ********":LPRINT
5 LPRINT
0 LPRINT " load reflection coefficient ":LPRINT :LPRINT
2 LPRINT TAB(5);"magnitude of Tlm";TAB(35);"angle of Tlm" : LPRINT
4 LPRINT TAB(10);TLMM;TAB(40);TLMA  : LPRINT : LPRINT
0 LPRINT "determination of load equivalent impedance"
5 LPRINT
0 LPRINT TAB(5);"magnitude of Zlo";TAB(35);"angle of Zlo" : LPRINT
2 LPRINT TAB(10);ZLOM;TAB(40);ZLOA  : LPRINT : LPRINT
0 LPRINT "impedances of the output matching network:" : LPRINT
2 LPRINT TAB(5);"Impedance associated with 3/8   is Z1";TAB(45);"Impedance as
iated with 1/4  is Z2" : LPRINT
4 LPRINT TAB(15);MZ1;TAB(55);MZ2
5 END
6 LPRINT "*********************  RESULTS  ********************"
0 LPRINT TAB(10);"Device is  HFET - ";TAB(31);DEVICE
0 LPRINT "Given S-parameters are:"
5 LPRINT
0 LPRINT TAB(5);"s11m";TAB(20);"s11a";TAB(35);"s21m";TAB(50);"s21a"
5 LPRINT
0 LPRINT TAB(5);S11M;TAB(20);S11A;TAB(35);S21M;TAB(50);S21A
0 LPRINT
0 LPRINT TAB(5);"s12m";TAB(20);"s12a";TAB(35);"s22m";TAB(50);"s22a"
```

```
LPRINT
LPRINT TAB(5);S12M;TAB(20);S12A;TAB(35);S22M;TAB(50);S22A
LPRINT : LPRINT : LPRINT
LPRINT TAB(7);"k";TAB(20):"magnitude of delta";TAB(45);"angle of delta" : L
T
LPRINT TAB(5);K;TAB(25);DELTM;TAB(50);DELTA
LPRINT "Frequency" : LPRINT
LPRINT FREQUENCY  : LPRINT
LPRINT
LPRINT TAB(5);"since k<1, the system is potentially unstable"
END
```

```
:EM PROGRAM TO CALCULATE Zo AND
:f.
I=25
:=10.2
.PRINT TAB(5);"W";TAB(30);"Ereff";TAB(50);"Zo"
'OR W=1 TO 100 STEP 1
:=W/H
:=(E+1)/2
:=(E-1)/2
:=(1+12/X)^(-.5)
F X<1 THEN 180
:1=A+B*C
.EM Ereff=((Er+1)/2)+((Er-1)/2)(1+12/X)**(-.5)
.G=(120*3.14)/(E1^.5)
I=X+1.393+.667*LOG(X+1.444)
Z=G/I
REM Zo=((120*3.145)/(Ereff** -.5))/(X+1.393+.667LOG(X+1.444))
LPRINT
LPRINT TAB(5);W;TAB(30);E1;TAB(50);Z
NEXT W
END
D=(1-X)^2
E1=A+B*C+.04*B*D
REM Ereff=((er+1)/2)+((Er-1)/2)[(1+12/X)^(-.5)+.04(1-X)^2]
G=LOG((8/X)+X/4)
I=60/(E1^.5)
Z=G*I
REM Zo=[60LOG((8/X)+X/4)]/(Ereff^.5)
GOTO 140
```

APPENDIX B

```
Program Microwave ( input,output );
{This program is used to design matching networks for  }
{low-noise microwave amplifiers.                       }
Type sparameters = array[1..2,1..2] of real;
Magnitude = array[1..2,1..2] of real;
Direction = array[1..2,1..2] of real;
Realn = array[1..2,1..2] of real;
imagn = array[1..2,1..2] of real;

Var
A,Deltafactor,delta1,delta2,delta3,delta4,rad,PI:Real;
Kfactor,frequency,deltaangle,A1,B1,B2: Real;
Mags: Magnitude;
Angle: Direction;
Rl: Realn;
Im: imagn;
I,J: Integer;
name,verify: char;
GmaoMag,GmaoAng,GmDf,GADA,C1,D1,RLGD,ImGD,GS11Mag:Real;
GS11Ang,C2,D2,D3,C3,DenoMag,DenoAng,NumMag,NumAng:Real;
GmLMag,GmlANg,GmLconjugate:Real;
Zo,Zsn1,Zsn2,Zsn3,Zsn4,Zsn5,ZsnMag,ZsnAng,SMag,
SAng: Real;
YsnMag,YsnAng,YsnReal,YsnIm,Zo1,Zo2: Real;
ZLn1,ZLn2,ZLn3,ZLn4,ZLn5,SLMag,SLAng,ZLnMag: Real;
ZLnAng,YLnMag,YLnAng,YLnReal,YLnIm,ZLo1,ZLo2: Real;

Procedure Poltorect;
Var unit1,unit2,unit3,unit4,rad: real;
Inter1,Inter2: Real;
stable,Kay,locus: boolean;
Begin
rad:=(PI)/180;
Unit1:= delta1*cos(delta3*rad);
Unit2:= delta1*sin(delta3*rad);
Unit3:= delta2*cos(delta4*rad);
Unit4:= delta2*sin(delta4*rad);
Inter1:= (unit1-unit3);
Inter2:= (unit2-unit4);
Writeln('the sum of [S11*S22-S12*S22] = ',
Inter1:6:5,' + j ',Inter2:6:5);
deltafactor:=Sqrt(sqr(Inter1)+sqr(Inter2));
Locus:= Inter1 < 0;
If locus then
    Deltaangle:=((Arctan((Inter2/Inter1))*(1/rad))+180)
else
    Deltaangle:=(Arctan((Inter2/Inter1))*(1/rad));
writeln('The deltafactor is ',deltafactor:6:5);
writeln('the deltaangle = ',deltaangle:5:2);
writeln('The next step is to calculate the Kfactor');
writeln;
Kfactor:=(1-Sqr(mags[1,1])-sqr(mags[2,2])+sqr(deltafactor))/
```

```
(2*delta2);
writeln('The K factor of the device = ',Kfactor:5:4);
stable:= Kfactor > 1;
Kay:= deltafactor < 1;
If stable then begin
  If kay then
    writeln('The device is unconditionally stable');
  end
else
  writeln('The device is potentially unstable');
B1:=(1+Sqr(mags[1,1])-sqr(mags[2,2])-sqr(deltafactor));
B2:=(1+Sqr(mags[2,2])-sqr(mags[1,1])-sqr(deltafactor));
writeln('B1 = ',B1:4:3,'  B2 = ',B2:4:3);
end; { Procedure Poltorect }

Procedure EchoOneLine;
var CurrentCharacter: Char;
begin
write('The Sparameters of the device ');
while not EOLN do begin
  read(CurrentCharacter);
  write(CurrentCharacter);
end;
writeln(' at ',frequency:4:2,' GHz. are');
end; { Procedure EchoOneline }
Function Realrect(mag,ang:real):real;
begin
Realrect:=(mag*cos(ang*rad));
end; { function Realrect }

Function Imrect(mag,ang:real):real;
begin
Imrect:=(mag*sin(ang*rad));
end; { function Imrect }

function size(A,B:real):Real;
begin
size:=sqrt(sqr(A) + sqr(B))
and; { function size }

function Shift(A,B:real):real;
Var Invert :Boolean;
begin
Invert:= A < 0;
If Invert then
  Shift:=(Arctan(B/A)) * (1/Rad) + 180
else
  Shift:=(Arctan(B/A)) * (1/Rad);
end; { function Shift }

Begin  { Program Microwave }
PI:= 3.141592654;
```

```
Rad:=( 2*PI)/360;
writeln('Enter the Center Frequency in GHz.');
Readln(frequency);
write('please enter the S parameters in polar form only');
writeln;
for I:= 1 to 2 do begin
   for j:= 1 to 2 do begin
   writeln;
      writeln('Enter S',i:1,j:1,' magnitude only');
        Readln(mags[i,j]);
         writeln;
         writeln('Enter S',i:1,j:1,' angle only');
       readln(angle[i,j]);
       Rl[i,j]:=(Realrect(mags[i,j],angle[i,j]));
     Im[i,j]:=(Imrect(mags[i,j],angle[i,j]));
   end;
end;
writeln;
writeln('Is this input data correct ???.');
writeln;
writeln('Enter the Magnitude of Gamma_o');
Readln(GmaoMag);
writeln('Enter the Phase of Gamma_o');
Readln(GmaoAng);
writeln('Enter the Characteristic Impedance of the Source');
Readln(Zo);
writeln('Enter the name of the device then "ENTER"');
EchoOneline;
for i:= 1 to 2 do begin
   for j:= 1 to 2 do begin
     writeln;
       write('S',i:1,j:1,' = ',mags[i,j]:4:3);
         write('  angle',i:1,j:1,' = ',angle[i,j]:4:3);
         writeln(' degrees');
       write('S',i:1,j:1,' in rectangular form is ');
     writeln(Rl[i,j]:5:5,' + j ',Im[i,j]:5:4);
   end;
end;
delta1:=(mags[1,1]*mags[2,2]);
delta2:=(mags[1,2]*mags[2,1]);
delta3:=(angle[1,1]+angle[2,2]);
delta4:=(angle[1,2]+angle[2,1]);
writeln;
Poltorect;
GMDf:=(GmaoMag*Deltafactor); {finds magnitude of Gmmao*delta}
GADA:=(GmaoAng+DeltaAngle); { Phase of Gammao*deltafactor}
write('The Deltafactor =',Deltafactor:1:4,' /');
writeln(Deltaangle:3:2);
writeln('GMDF = ', GMDF:1:4);
writeln('GADA = ', GADA:1:4);
RLgd:=Realrect(GMDf,GADA); { Change to rectangular form }
IMGD:=Imrect(GMDf,GADA); { The Imaginary part }
```

```
writeln('The Real part of Gamma_o*Delta =',RLGD:1:4);
writeln('The Imaginary part = ',IMGD:1:4);
C1:=(Rl[2,2] - RLGD); { Real part of S22 - Gammao*Delta}
writeln('The real part of S22 - Gamma_o*Delta =',C1:1:4);
D1:=(Im[2,2] - ImGD); { Imag part of S22 - Gammao*Delta}
writeln('The Imaginary part of Gamma-o*Delta =',D1:1:4);
GS11Mag:=(GmaoMag*Mags[1,1]); {Magnitude of Gmmao*S11}
GS11Ang:=(GmaoAng+Angle[1,1]); { Phase of Gamma_o * S11 }
C2:= Realrect(GS11Mag,GS11Ang); {Real part Gmma_o*S11}
D2:= Imrect(GS11Mag,GS11Ang); { Imaginary part }
writeln(' D2 = ***** ',D2:1:4);
C3:=(1-C2); { real part of 1 - Gamma_o * S11 }
D3:= - D2;
writeln('The real part 1-Gamma_o*S11=',C3:1:4);
Denomag:= Size(C3, D3); { Magnitude of C3 }
writeln('The Magnitude of C3 = **', Denomag:1:4);
DenoAng:= Shift(C3,D3); { Phase of C3 }
writeln('The Phase of C3 = ', DenoAng:1:4);
Nummag:= Size(C1,D1); {Magnitude of S22 - Gamma_o*Delta }
writeln(' The Magnitude of the numerator =',Nummag:1:4);
NumAng:= Shift(C1,D1); { Phase of S22 - Gamma_o * Delta }
writeln('The Phase of the numerator =',NumAng:3:2);
GmLmag:=(NumMag/DenoMag);
GmLAng:=(NumAng - DenoAng);
GmLConjugate:= - GmLAng;
If GmLConjugate <= -180 Then
   GmLConjugate:= GmLConjugate + 360;
writeln('GammaL = ',GmLmag:1:4,' /',GmLconjugate:3:2);
writeln;
Zsn1:=Zo*(1-Sqr(GmaoMag)); { Real part of the numerator }
Zsn2:=2*Zo*Sin(GmaoAng*Rad);{ Imaginary part }
Writeln('The Numerator is ',Zsn1:1:4,'+j',Zsn2:1:4);
SMag:=Size(Zsn1,Zsn2); { Magnitude of the numerator }
SAng:=Shift(Zsn1,Zsn2);{ Phase of the numerator }
writeln('In Polar form Numerator =',SMag:1:4,'/',SAng:3:2);
{ writes the numerator in polar form }
Zsn3:= 1+Sqr(GmaoMag);
Zsn4:= 2*GmaoMag*Cos(GmaoAng*Rad);
Zsn5:= Zsn3 - Zsn4;
ZsnMag:= SMag/Zsn5; {Finds the  magnitude of Zsn }
ZsnAng:= SAng;
write('The Source equivalent impedance for minimum-noise');
writeln(' figure is Zsn');
writeln(' Zsn = ',ZsnMag:1:4,' /',ZsnAng:3:2);
writeln('The next step is to convert Zsn to Ysn');
YsnMag:=(1/ZsnMag);
YsnAng:=(-ZsnAng);
writeln('Ysn in polar form = ',YsnMag:1:4,' /',YsnAng:3:2);
YsnReal:= Realrect(YsnMag,YsnAng);
YsnIm:= Imrect(YsnMag,YsnAng);
write('In rectangular form Ysn= ',YsnReal:1:4,'+j ');
writeln(YsnIm:1:4);
```

```
{ The next step is to utilise an open-circuited }
{ A three-eights wavelength stub which looks like }
{ a shunt inductor of susceptance - j Yo.       }
Zo1:= ( 1/Abs(YsnIm));
writeln('Zo1 = ',Zo1:3:3, ' Ohms');
{ The next step is to use a quarter-wave Transformer }
{ to transform the load resistance of 50 Ohms to the }
{ load equivalent conductance of Ysn (Real).        }
Zo2:= Sqrt(Zo/Abs(YsnReal));
writeln('Zo2 = ',Zo2:3:3,' Ohms');
ZLn1:=Zo*(1-Sqr(GmLMag)); {Real part of numerator}
ZLn2:=2*Zo*Sin(GmLAng*Rad);{ Imaginary part }
Writeln('The Numerator is ',ZLn1:1:4,'+j',ZLn2:1:4);
SLMag:=Size(ZLn1,ZLn2); { Magnitude of the numerator }
SLAng:=Shift(ZLn1,ZLn2);{ Phase of the numerator }
writeln('In Polar form Numerator =',SLMag:1:4,'/',SLAng:3:2);
{ Writes the numerator in polar form }
ZLn3:= 1+Sqr(GmLMag);
ZLn4:= 2*GmLMag*Cos(GmLAng*Rad);
ZLn5:= ZLn3 - ZLn4;
ZLnMag:= SLMag/ZLn5; {Finds the  magnitude of Zsn }
ZLnAng:= SLAng;
write('The load equivalent impedance for minimum-noise');
writeln(' figure is ZLn');
writeln(' ZLn = ',ZLnMag:1:4,' /',ZLnAng:3:2);
writeln('The next step is to convert ZLn to YLn');
YLnMag:=(1/ZLnMag);
YLnAng:=(-ZLnAng);
writeln('YLn in polar form = ',YLnMag:1:4,' /',YLnAng:3:2);
YLnReal:= Realrect(YLnMag,YLnAng);
YLnIm:= Imrect(YLnMag,YLnAng);
write('In rectangular form YLn= ',YLnReal:1:4,'+j ');
writeln(YLnIm:1:4);
{ The next step is to utilise an open-circuited }
{ Three-eights wavelength stub which looks like }
{ a shunt inductor of susceptance - j Yo.       }
ZLo1:= ( 1/Abs(YLnIm));
writeln('ZLo1 = ',ZLo1:3:3, ' Ohms');
{ The next step is to use a quarter-wave Transformer }
{ to transform the load resistance of 50 Ohms to the }
{ load equivalent conductance of YLn (Real).        }
ZLo2:= Sqrt(Zo/Abs(YLnReal));
writeln('ZLo2 = ',ZLo2:3:3,' Ohms');
end.  { end of program microwave }
```